WATER QUALITY MANUAL

Richard B. Howell

Associate Materials and Research Engineer

Earl C. Shirley

Supervising Air Pollution Research Specialist

John B. Skog

Supervising Materials and Research Engineer

John L. Beaton

Materials and Research Engineer

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Manual is used in conjunction with training course in slope erosion surveys.

16. ABSTRACT

Several methods of estimating slope erosion rates are discussed briefly and the slope erosion transect method is presented in detail. The survey procedure consists of identifying erosion signatures on existing highway slopes such as root exposure, curvature of stems of plants growing on slope surface, overhang near top of cut, etc. Estimates are made of the erosion that has taken place since construction of the slope and from the most recent year. Average annual slope erosion rates for long term and short term periods are compared to determine if erosion is accelerating, decelerating or near normal.

Erosion rates in units of cubic yards/square foot/year can be applied to yet unconstructed slopes on a planned highway near the site of the survey to estimate probable quantities of sediment. If significant quantities of sediment are expected, remedial measures can be planned to reduce the estimated impact.

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FOREWORD

A number of studies must be completed prior to the writing of an Environmental Impact Statement for a highway project. One of these is a Water Quality Study. This manual is the fourth in a series of five manuals designed to assist the districts in accomplishing this task with respect to Water Quality. It is intended to provide a method for determining potential erosion quantities from highway slopes. References are listed which are more complete in the discussion of the subject matter.

The titles of the five manuals in this series are as follows:

1. Analysis of Water Quality for Highway Projects

2. Glossary

3. A Method for Analyzing and Reporting Highway Impact on Water Quality

4. Highway Slope Erosion Transect Surveys

5. Chemical, Biological, and Aquatic Biota Analysis of Water From Highway Sources for Environmental Impact Studies

Manuals 1, 2 and 3 are being used in one-week training courses for district personnel by the Environmental Improvement Section of the Materials and Research Department. Manual 4 will be used in a three-day training session and Manual 5 will be used for an Advanced Water Quality Course scheduled to begin in the summer of 1973.

ACKNOWLEDGEMENT

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Special acknowledgement is given to Don Foster and Richard Wasser of District 03 who assisted on a slope erosion survey in the Tahoe Basin during 1971.

FIGURES

INTRODUCTION

One of the environmental impacts resulting from highway projects is erosion of cut and fill slopes and the subsequent sedimentation of water courses and hydraulic structures. As an example, in California, studies by the U. S. Soil Conservation Service show that 108,100 cubic yards/year of sediment is produced from roads in the Eel River Basin[1]. In the Dry Creek Watershed of the Russian River Basin, 5,324 cubic yards of sediment annually comes from slopes on 34.9 miles of main (paved) roads[2]. State highways in the Lake Tahoe Basin account for approximately 1,218 cubic yards/year[3].

Sediment can adversely affect aquatic biota in numerous ways. The murky appearance of the water that occurs after a rain storm results in a reduction of light transmittance which affects fishery resources[4]. Depletion of dissolved oxygen and the abrasive action of sediment on the gills of fish have also produced adverse effects. Deposition of sediment on channel bottoms can alter the usefulness of gravels that are necessary for spawning and also the habitat required for macroinvertebrate and aquatic plant life.

Decreased channel conveyance capacities during peak discharge periods occur from the continued deposition of sediment. The cleaning of culverts and other hydraulic structures are common maintenance practices necessitated by such deposition. The cleaning of eroded material from side ditches of roads is a major maintenance expenditure in some areas.

Nutrients and minerals are known to be associated with the sediment discharges. Particularly, soil eroded from roots of established plants and trees may provide significant amounts of nitrates and phosphates to receiving waters. Other biostimulatory ingredients may also be contained in the sediment. In some instances, dissolved metals may impart a toxic effect to the water.

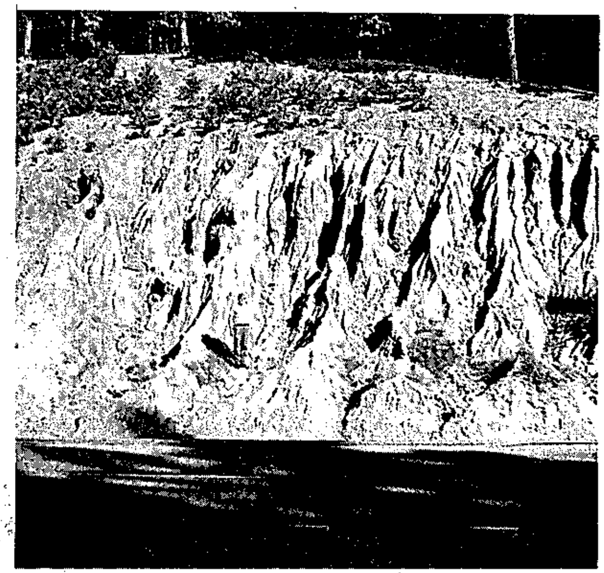
This manual presents some of the current techniques used to develop annual sedimentation rates or total erosion quantities for highway slopes. Other practices are used which are not covered in this report, however, the method outlined should provide sufficient information to conduct a satisfactory survey. The manual goes into detail on the "Slope Erosion Transect" procedure which is used on a broader scale by other agencies for total watershed analyses of sediment rates. It has been specifically adapted in this publication, for highway slopes.

The information generated from the erosion survey can be used as input to a water quality study for estimation of erosion rates on new slopes. The estimated future sediment quantities, when compared with existing sediment transport quantities in streams, can be used to predict probable impact of proposed highway projects for use in the planning stage, indicate the need for design mitigation of impact, and provide construction and maintenance with the necessary information to protect water quality during their activities.

Factors Affecting Erosion

Most slopes undergo some form of geologic erosion. This is how many valleys have been formed and scenic canyons created. Accelerated slope erosion occurs when elements are significantly changed such that the erosion is notably increased over the normal rate. In many cases, the increased slope erosion is attributable to man's activities.

Evidence of accelerated slope erosion is seen by deep gullies and rills that form on unprotected slopes. Undercutting of top edges of cut slopes is also a sign of accelerated erosion. Sheet erosion is the uniform removal of material over the slope and consequently is sometimes difficult to detect.



GULLY EROSION ON ROAD SLOPE

Factors affecting erosion include climate, meterology, geology, pedology, topography, groundcover, and land use[5]. Figure 1 shows some of the processes involved directly in the erosion of a road slope.

Generally, raindrop impact is a predominate force in the initial erosion process. Traveling at a velocity of about 19 miles per hour, the raindrops explode on the slope like tiny bombs[6]. The energy released through the impact results in soil particles being displaced. As surface flows increase and saturation of the slope material occurs, the detached soil particles tend to be transported downslope. This process may encumber a large or small time frame dependent on the precipitation pattern.

Other factors that also encourage the erosion include wind, freeze-thaw action, and chemical reactions. The weathering processes are continually at work. The complex subject of chemical weathering can be explored further in appropriate textbooks[7].

Land use plays an important role since activities above the road slope such as the removal of groundcover from logging, land development, grazing or fire, can increase infiltration and runoff rates[6]. The impermeable pavement surface also leads to an increase runoff during rainstorms and may influence erosion of drainage facilities located downstream.

In deriving slope erosion estimates, it is important to consider future land use as well as current practices. Future activities on adjacent lands may result in additional erosion for the soil type and climatic conditions encountered. It is important to remember that soil erosion rates developed in this manual represent existing conditions and are not estimates of the maximum rates that could be obtained under the most unfavorable conditions.

The slope erosion transect process attempts to identify evidence of erosion, or erosion signatures, on the slope face which will allow a reasonable estimate to be made of annual amounts of eroded material.

TYPICAL PROCESSES INVOLVED IN SLOPE EROSION

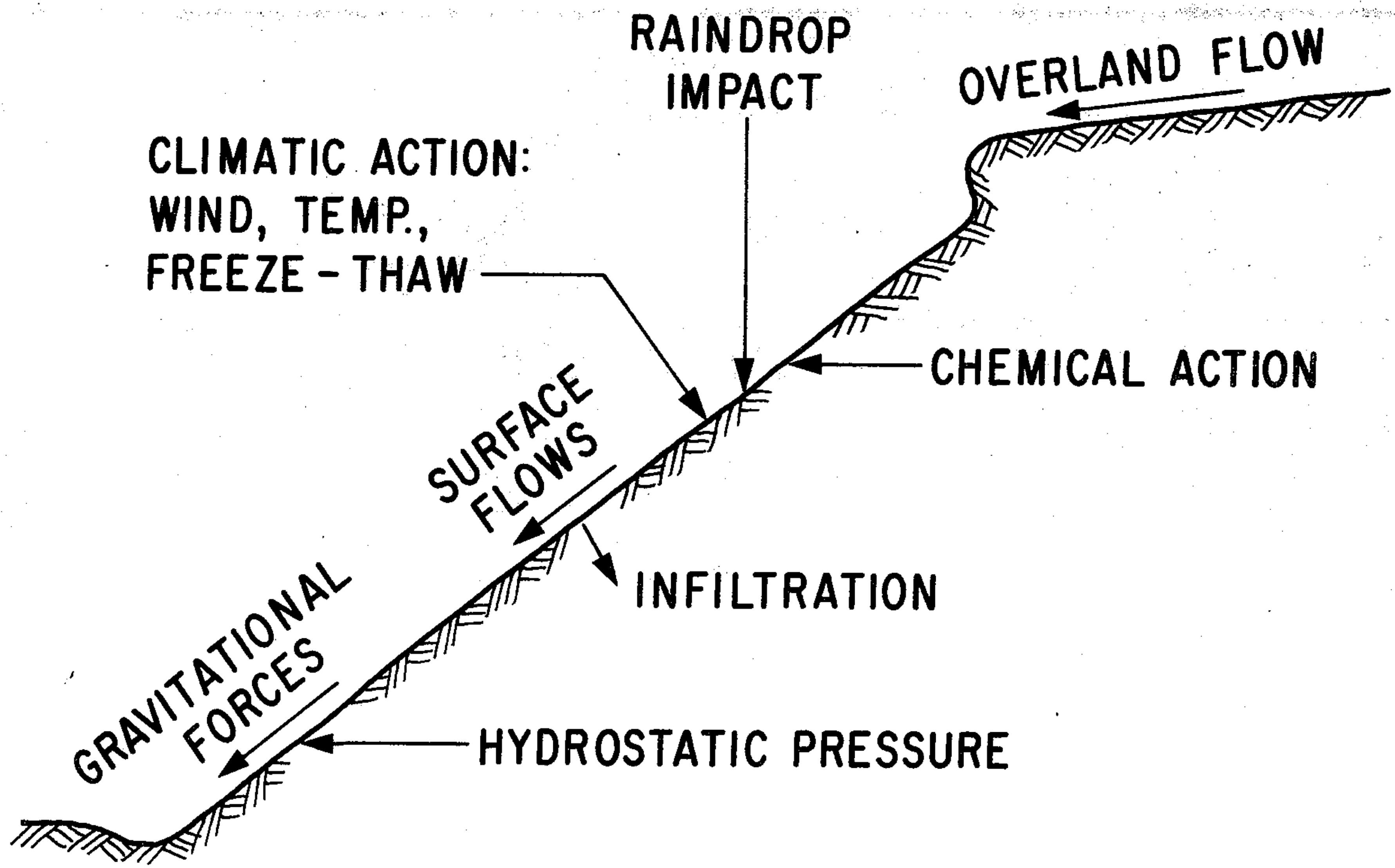


Figure 1

METHODS FOR CONDUCTING EROSION SURVEYS

There are several methods by which slope erosion can be estimated. The use of any of these techniques will be determined by the resources available to the investigator. For highway slope erosion estimates, it is recommended that the slope erosion transect method be used. It is discussed under (6) below and is presented in detail in the next section. The first five methods discussed in this section (below) present alternative means that may be applicable in some circumstances.

1) Cross Sectioning

For slopes that exhibit precise evidence of erosion such as rills and gullies or a significant removal of a uniform layer of surface material, a series of cross sections of the slope over a specified time period will yield detailed information on erosion. Generally, reference survey points must be established in the slope and at adjacent points. A rod and level are then used to measure existing elevations on the slope. Unfortunately, most slopes have such irregular shapes that the recordation of elevations is very difficult. However, in order to measure erosion over a time period, as many elevations as possible should be recorded.

At selected time intervals such as monthly, or after certain significant storm periods, elevations on the slope are read again. These measurements are compared to the original elevations and the differences are interpreted to develop an erosion rate. In some instances, slope elevations will appear to increase rather than decrease as one would suspect as material is eroded. This is caused by eroded material accumulating at specific points as the material moves downslope. Thus, all readings must be interpreted in relation to elevations recorded at adjacent points.

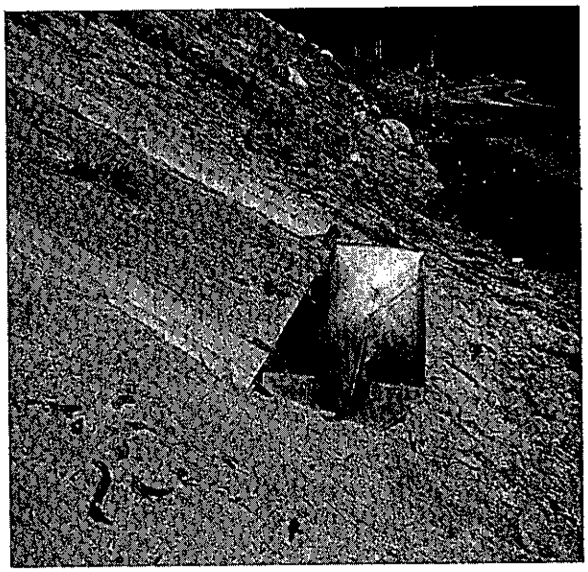
In some cases, a small test plot can be established on the slope and changes in slope elevations observed over a specified time interval through the use of a mechanical slope template[8]. This method consists of measuring on a one-foot by one-foot grid system the elevations of the slope surface after each storm period. The changes in elevation are analyzed to yield the quantity of eroded material.

The actual layout of survey points will be dependent on the slope configuration. Therefore, no set pattern is recommended as ideal. It is suggested that survey points be established in a grid-type system for ease in comparing elevations. But again, there may be significant points between the grids that one may wish to record. These determinations must be made in the field.

2) Sediment Collection Devices

Another useful technique for determining slope erosion quantities is a direct measure of the sediment as it is eroded. This can be done with various sediment collection devices such as stilling basins, hydraulic settling channels and sediment collection troughs. For measuring erosion from a specific highway slope, a sediment collection trough may be used.

Usually the area of a slope is too large and the rate of erosion too great to attempt to collect all the sediment. In this case, a portion of the slope is marked off and a sediment collection trough is then located at the base of the "plot".



SEDIMENT COLLECTION TROUGH ON HIGHWAY SLOPE NEAR LUTHER PASS, HIGHWAY 89 IN TAHOE BASIN (9)

The volume of the trough is designed such that, for a designated hydrologic event, the runoff volume of water and sediment will be retained in the trough. The water will gradually seep through small holes bored in the sides and bottom. The sediment is removed periodically for weighing and other analyses such as grading and specific gravity.

The sediment information derived from the test plot is then interpreted for the entire slope under investigation. An analysis of the slope must be made to determine which areas of the slope contributed the sediment and in what proportions. Utilizing this information, the net quantity of eroded material can be estimated.

In determining annual slope erosion quantities in this manner, it must be remembered that the sediment collected was derived from hydrologic events that occurred during the period of observation. Thus, the analysis of the data will not yield information for other periods of time even though it is evident that in the past significant slope erosion may have occurred.

A precipitation gage frequently must be installed in order to gather climatological data since the interpretation of sediment data is dependent on hydrologic conditions for the period of observation. For example, if an unusual condition existed where no rainfall occurred during the period of study and consequently no sediment was collected in the trough, the information could be interpreted accordingly. However, if no precipitation data was available, an incorrect conclusion could be reached in the analysis.

The sediment collection device will not normally yield sediment information related to wind erosion.

3) <u>Remote Sensing</u>

The primary method of determining slope erosion by remote sensing is through the use of oblique photographs. Pictures taken from the same point of a road slope over time will present information such as changes in slope configuration, rocks that have rolled down and other related items that can be used to subjectively assess the quantity of eroded material.

Pictures of hydraulic facilities, either natural or man-made, can be used to show a gradual accumulation or scouring of material from a road slope.

Other techniques that are used include underwater photography to record movement of bed material and delta buildup, and aerial surveillance of water courses that relate sediment plumes to ground truth data. Other signatures can be used to correlate sediment transport with photographic imagery. The reader should refer to appropriate references for more detailed information[10].

4) Maintenance Records and Interview

Evidence of past erosion on a slope is sometimes very difficult to obtain because of changing conditions that hide erosion signatures. Particularly, if it is desirable to relate slope erosion quantities with precipitation information, it may be that maintenance operations have changed the slope surface whereby signatures that are now revealed are not indicative of past events.

In these cases, it may be desirable to interview individuals who have some knowledge of activities that have occurred on the slope in times past. Frequently, people who have worked or live near the area in question can provide the best possible information.

Division of Highways maintenance personnel generally can indicate the magnitude of erosion problems for various slopes. Although this type of information is highly subjective, a fairly good idea of sediment rates can be gathered.

If records are available that reveal statistics relating to the amount of work required to maintain specific slopes, this information then too can be gleaned to arrive at a conclusion as to past erosion rates. This procedure is analogous to hydrologic studies involving flood surveys.

Areas where eroded material has been deposited in the maintenance operation can also be surveyed. The number of years in which the disposal site has been used combined with the volume of material present will give some idea of the annual sediment rate.

5) Erodibility Indices

There are various soil erodibility formulas that provide an indication of potential soil erosion. Two of these formulas discussed below were developed by W. H. Wischmeier[11] and the U. S. Soil Conservation Service[12]. Although these formulas are not intended specifically for a highway slope, they do include several factors that are involved in the erosion process and have provided sufficient accuracy on farmland and other areas when properly interpreted. It is not recommended that these formulas be applied without further analysis. They are presented here to show the general underlying concepts. Further information can be obtained from the references.

The W. H. Wischmeier equation, which was developed originally for farmland east of the Rocky Mountains, is as follows:

$$E = R\,K\,L\,S\,C\,P$$

Where:

E = Average Annual Soil Loss (tons/acre)

R = Rainfall factor expressing the erosion potential of average annual rainfall in the locality (Wischmeier and Smith).

K = Soil erodibility factor. Values are generally 0.02 to 0.70 tons per acre per unit of rainfall factor R.

S and L = Topographic factors for adjusting the estimate of soil loss for a specific land gradient and length of slope.

C = Cropping management factor. Represents the ratio of the soil quantities eroded from land that is cropped under specific conditions to that which is eroded from clean-tilled fallow under identical slope and rainfall conditions.

P = Supporting conservation practice factor. For straight-row farming, P = 1.0.

Appropriate nomographs have been developed for ease in determining the various factors in the equation[13]. However, the assumptions used in developing the nomographs should be reviewed prior to the application of this procedure to a slope erosion study.

Another formula that has been developed for predicting erosion rates is as follows[12].

$$E = FR_e \left(\frac{P_{30}}{1.25}\right)^{1.75} \left(\frac{S_L}{10}\right)^{1.35} \left(\frac{L}{72}\right)^{0.35}$$

Where:

E is the long-time average annual soil loss or rate of sheet erosion, in tons per acre or in inches of average depletion.

F is the basic soil erodibility factor, in the same units as E.

R_e is a relative erosion rate for different types of vegetal cover and agricultural practice.

P_{30} is the maximum precipitation, in inches, in a 30-minute period for a recurrence interval of 2 years.

S_L is the average slope of the land surface, in percent.

L is the length of the slope, in feet, in the direction of flow.

It is apparent that these various relationships attempt to consider pertinent parameters that effect erosion in some numerical manner. Explicit use of any such relationship should be investigated further and perhaps adjusted to fit the particular set of circumstances that are encountered for a project.

6) Slope Erosion Transect Survey

The slope erosion transect survey is a procedure whereby existing slopes are examined to determine average annual erosion quantities which can then be applied with certain adjustments to slopes that may be constructed in the vicinity. This method allows the interpretor to see first hand the problem erosion characteristics that will develop on a future slope unless specific remedial measures are employed to alter these characteristics.

The slope erosion transect survey can also be used to compare erosion quantities from existing slopes with those from other slopes in a given location. This may be particularly useful information if a remedial program is to be implemented in an attempt to mitigate present environmental impacts, aesthetic problems, or maintenance effort.

The following section deals exclusively with the slope erosion transect process and provides detailed instructions for conducting the survey.

PROCEDURE FOR SLOPE EROSION TRANSECT SURVEY

Normally, slopes are chosen within the same watershed crossed by the future road alignment. This tends to minimize the effect of variables such as rainfall patterns, temperature, vegetative cover, etc. which might result from the selection of slopes in a different watershed. Once the area for the erosion survey is decided, local roads can be examined to determine slopes that will be studied. Generally, slopes are selected that appear to be similar to those that will be constructed. Similarity should include slope angles, exposure, height of slope and area exposed and slopes that are subjected to similar precipitation. If state highway slopes are not available, other local road slopes can be examined such as country, city or subdivision roads, forest roads, etc.

Preview of slopes on designated sections of State highways should utilize the microlog film (a photographic log of the roadway taken every 50 feet). Although all road slopes are not readily visible in the frames, a general idea of the slope characteristics can be gained. The post mile limits can be obtained from the picture frame for those slopes that may be investigated further in the field.

When a slope has been selected for the survey, areas are cordoned off that have representative features. In some cases, the slope may appear to be uniform throughout its length. In others, there may be obvious differences between the lower and upper portions of the slope or along its length. In order to derive an erosion rate in these instances, typical areas should be selected and examined independently of the other portions.

The erosion rates derived for each representative area can then be applied over that portion of the slope that they represent and then summed to obtain a total rate for the slope. For particularly large slopes, it is difficult to estimate an erosion rate for the total slope without investigating several smaller areas first. Erosion signatures can vary quite a bit depending upon the erosion rate at that section of the slope. For these reasons, the process of dividing the slope into smaller sections will help derive a more accurate rate for the total area.

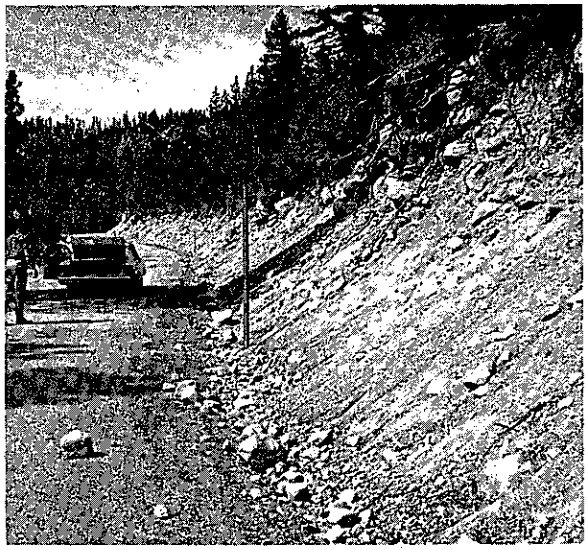
Discussed below are four major items that should be noted and examined in depth for the selected area on the slope. These have been classified as follows: 1) vegetation, 2) soil, 3) slope configuration, and 4) other. There may be additional categories that will assist in arriving at a conclusion as to the probable annual slope erosion rate such as meterological factors, but these will have to be identified for individual slopes as to whether they are needed.

1) Vegetation

A good indication of the rapidity of erosion is the degree or extensiveness of ground cover. If erosion is low, vegetation will usually have a much greater opportunity to proliferate on the slope than if the erosion rate is moderate to severe. There may be other factors on the slope that preclude plant or grass establishment such as soil nutrition, seed availability, moisture, soil parent materials, etc., but these conditions can generally be detected by observing the region to see if other similar areas are also sparsely vegetated. If dense vegetation occupies the surrounding terrain and the slope is bare, chances are that erosion rates are sufficient to prevent a good plant cover. Size of plant material may also give clues as to the amount of soil movement. For example, if vegetation is immature and the slope has been in existence for a long period of time, it may be that the rate of the erosion process does not allow vegetation to become established.

Curvature of the stem of small woody plants will give a good indication of the movement of bank material downslope. The force of the moving soil pushes against the base of the stalk and tends to push it downslope. However, the vegetation seeks to grow in an upright position and thus a curved stem results. One must be careful to distinguish between curvature caused by soil erosion and that caused by snow load, wind, and rotation of the soil mass as in an unstable slope and other soil factors.

A third signature that will provide significant information is the exposure of roots of existing vegetation. As the surface material on the slope erodes, the top of the slope is undercut thus exposing the previously buried roots from top of cut vegetation.



UNDERCUTTING OF TOP OF SLOPE
EXPOSING FORMERLY BURIED ROOTS
OF TOP OF CUT PLANTS

In some cases, as the soil is eroded around the root, exposure to the atomosphere results in a differential coloration on the root. The portion recently exposed appears as a lighter color than the root portion that has been exposed for a longer period.

The length of the root segment can be measured to determine the distance the slope surface has receded since construction. By examining the differential coloring effect, it may be possible to detect the exact amount of recession over a given period. This may be helpful in estimating whether erosion is steady, accelerating or decelerating compared to the initial rate.

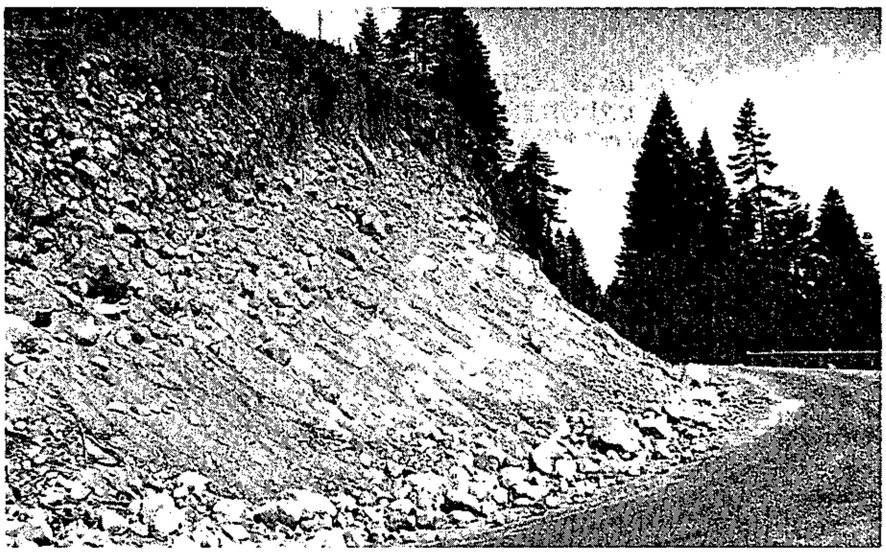
During construction, some trees near the top of a slope may have been cut, leaving a stump. On the constructed slope, roots may have been cut parallel with the slope surface. As erosion subsequently progressed many of these stumps and their root system have been severely undercut. In these cases, measurements can be taken of the amount of undercutting to estimate slope erosion since the time of construction.

2) Soil

The type of erosion occurring on the slope is generally rill, gully or sheet erosion. Gully and rill erosion present the most readily measurable form of erosion. In these instances, the depth, width, and length of each rill can be measured to determine the volume of eroded material. Again, if the slope area is quite large, smaller representative sections of the slope may be selected for measurment and the result then applied over the total surface area.

Sheet erosion, which is a uniform removal of material from the slope face, is more difficult to detect and subsequently quantify. Generally, other signatures such as root exposure and differential coloration can be used to detect sheet erosion.

As soil is eroded from the upper regions of the slope, a gradual accumulation may occur at points on the lower portion of the slope.

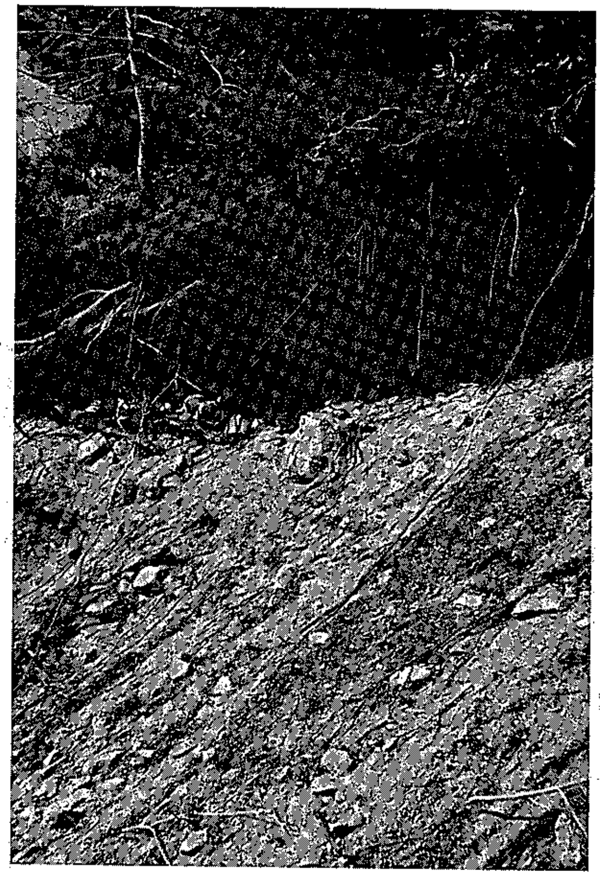


ACCUMULATION OF SEDIMENT IN LOWER PORTION OF CUT SLOPE

On a smaller scale, sediment will accumulate behind larger stationary objects on the slope such as rocks and vegetation. Commonly, these smaller signatures indicate the degree of recent movement.

Larger vegetative species such as bushes will trap significant amounts of sediment around the base of the plant. Generally, these areas provide a good indication of recent erosion. Continued weathering and precipitation will tend to wash the sediment particles away and consequently this signature is normally a revelation of erosion from the latest series of storms.

If protective covering such as rock or vegetation inhibits erosion near the top of a cut, undercutting of this area may take place.



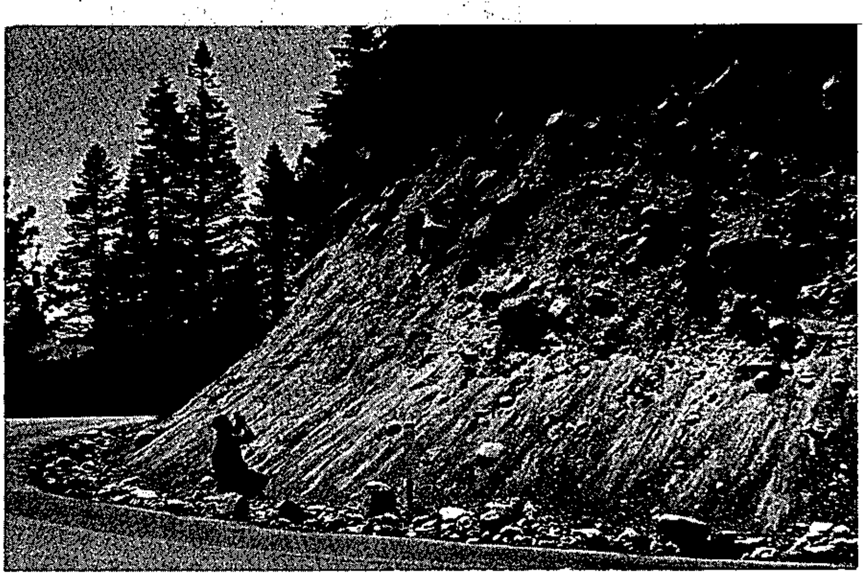
UNDERCUTTING OF STABLE SURFACE
AREA ON ROAD CUT

By projecting an imaginary line from the catch point near the top of the slope downward to the constructed toe of slope, it is possible to estimate the approximate quantity of material that has eroded since construction of the cut.

Discoloration of rocks that are semi-permanently fixed in the slope surface also indicates a rate of erosion. Normally, the longer a rock is exposed to atmospheric conditions and especially sunlight, the more "bleached" the appearance. The buried portion retains a darker color and thus a distinct layered look may be evident on some rocks as the slope material is eroded.

3) Slope Configuration

In very erodible slope materials with a protective vegetative cover above the cut slope, an undercutting will normally occur with a resultant sediment buildup near the toe of the slope. This concave configuration provides a stabilizing action on the slope.



CONCAVE SLOPE CONFIGURATION DUE TO UNDERCUTTING OF TOP OF CUT AND POSITION NEAR BOTTOM

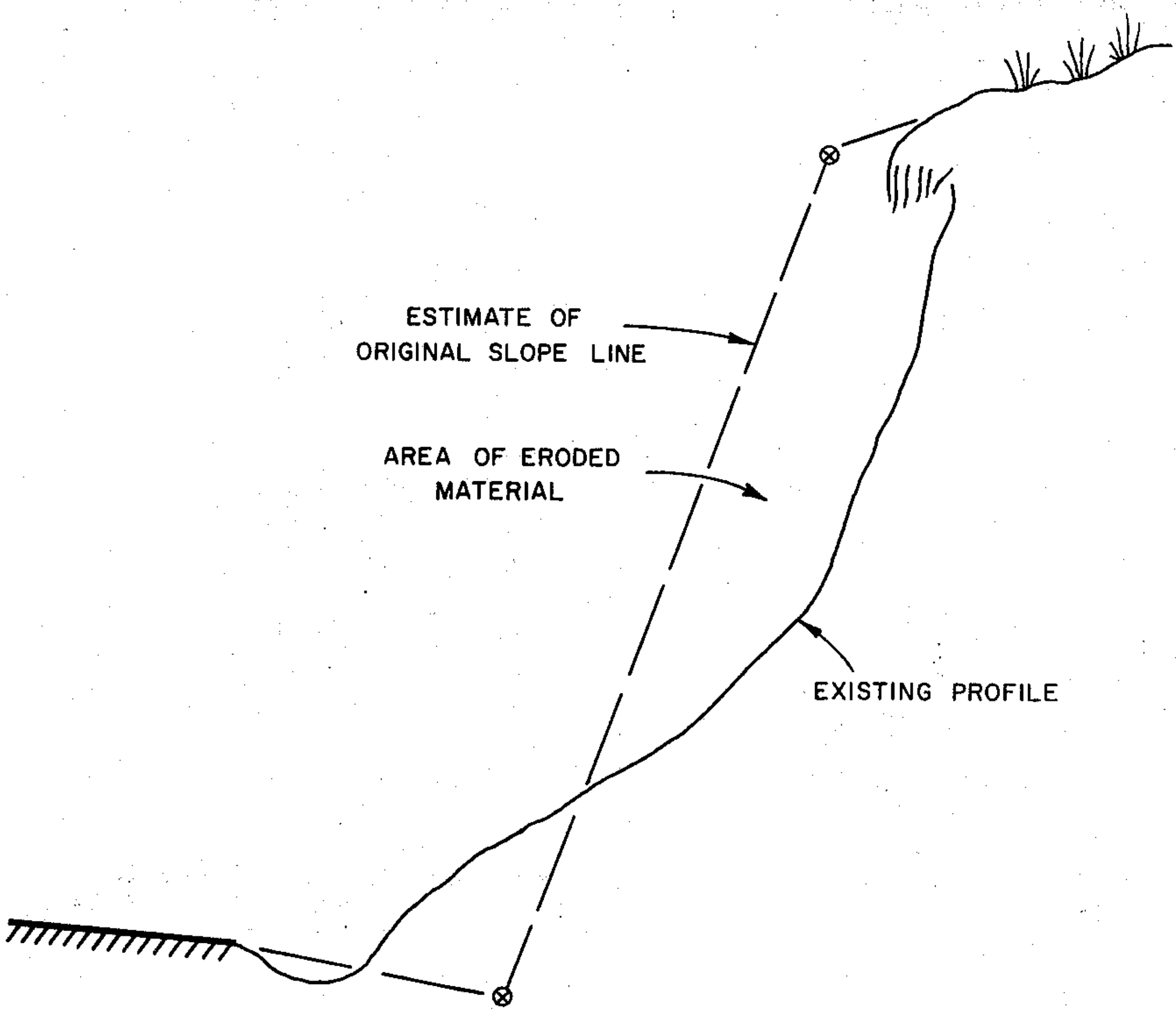


Figure 2 SLOPE COMPARISON

By projecting a line from the top of the cut to the toe as originally constructed, a comparison can be made to determine the amount of material eroded over that time span. Figure 2 illustrates this principle.

Significant washing of material is also used to provide an estimate of erosion activity. In some cases, the material appears as an alluvial fan near the base of the slope.

ACCUMULATION OF ERODED SEDIMENT
ON FILL SLOPE WITH APPEARANCE OF
ALLUVIAL FAN

Other washing action may transport material to hydraulic structures and result in deposition at those points. This action is discussed under the fourth item "Other".

4) Other

There are several additional erosion signatures that are useful in estimating rates. Buried leaves, pine needles, and seed provide a good indication of the movement of soil from points upslope. Particularly leaves or pine needles that have fallen the previous season may be buried under several inches of freshly eroded soil as it moves downslope. Careful scraping away of slope material will reveal these important erosion signatures. The quantity of material overlying these objects can be calculated by measuring the depth from the surface to the leaf and multiplying that by the representative area.

Also, as organic material decomposes under bacterial action, the color normally becomes dark brown to black as opposed to a freshly fallen leaf which is generally yellow or light brown. Analyzing the color of the organic material may help determine the time interval since burial. Other factors such as moisture, temperature, etc. must be considered, however, in ultimately estimating a time period.

With slope erosion, the slope gradually recedes into the hill. As the process continues, overburden material may cascade over the top of cut and onto the slope surface. The appearance of the overburden material is generally markedly different than that of the surrounding slope material. It may also be accompanied by other debris such as humus, twigs, and other vegetative species.

Chemical weathering of material is an important aspect of the erosion process. Hard soil or rock materials may not appear to yield significant erosion quantities, however, they should be closely examined for possible deterioration. Decomposed granite is a good example of a material that can yield measurable quantities of sediment as the hardened rock is chemically weathered at the surface.

Some erosion on a slope may be precipitated by seepage. If apparent moisture regions appear, they may provide clues as to probable erosion. In some cases, however, seepage may help inhibit erosion by enhancing vegetative growth.

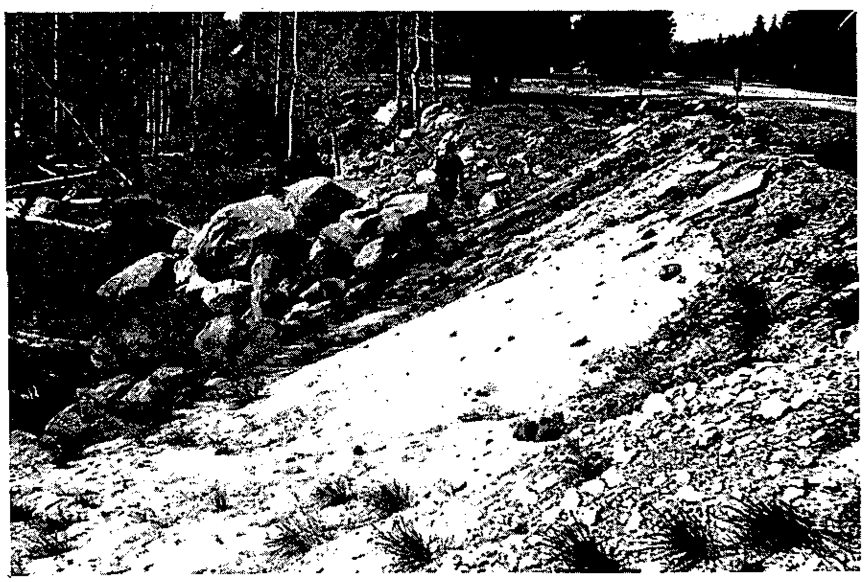
Other forms of erosion may include slipouts and slides although categorically they are often referred to as structural slope failures. The extent of sediment from these sources must be determined directly from measurements.

Another method of estimating erosion is to estimate the quantity of sediment that accumulates at hydraulic structures such as culvert inlets.

SEDIMENT DEPOSITION AT CULVERT INLET

Commonly the entrance to the crossdrain becomes blocked with debris. Consequently, velocities are reduced and the sediment laden water deposits its load. The accumulated material can provide an estimate of the quantity of eroded material.

At some slopes, eroded material is removed during maintenance to insure efficient functioning of road ditches and provide safety for the motoring public. If the areas where this material is wasted are known, the volume of material can be measured which again will indicate the probable quantity of eroded material.



ERODED SEDIMENT FROM ROAD CUT SIDE-CAST OVER NEARBY ROADFILL. NOTE LIGHTER COLOR OF MATERIAL AS CONTRASTED TO ORIGINAL FILL

It may be helpful to ascertain when the maintenance operation took place in order to gain some idea of the rate of erosion with respect to time.

1) Determining Annual Erosion Rate

It is often beneficial to determine an annual erosion rate by estimating the erosion that took place during the most recent year and determining the quantity of erosion that has occurred since the slope was constructed. These two rates are called Short Term and Long Term Annual Erosion Rates. A comparison between the two rates usually indicates one of the following:

Short Term <Long Term	Initial erosion on the slope was more rapid and conditions have changed sufficiently that annual erosion is decreasing.
Short Term ≅Long Term	Erosion apparently is continuing at the same rate as initial construction rates.
Short Term >Long Term	Annual slope erosion is increasing compared to initial rates. It may be beneficial to discover the reason for the increase.

In the case where short term erosion rates greatly exceed the long term annual rate, the conditions around the slope should be investigated to determine the cause for the increase. Factors that may lead to an increased rate may be attributable to above average precipitation; increased runoff from upslope sources (overland flow); changed inland use above the cut (increased runoff or decrease in transpiration, etc.); construction on the slope, etc. There may be mitigation measures that could be installed to bring the rate back to, or lower than, the long term computed rates.

A. Short Term Average Annual Rate

The short term average annual erosion rate can be determined from the following relation:

$$\text{Short Term Annual Erosion} = \frac{\text{Recent Quantity of Eroded Material}}{\text{One year (or less)}}$$

In this formula, the quantity of eroded material is that amount which can be identified as being produced within the last hydrologic cycle (October 1 to September 30) or shorter time period. If a shorter time period is used, such as 6 months, the decimal equivalent 0.5 is used. The units are usually reported as tons/years or cubic yards/year.

Determining quantities of eroded material maintenance removes from the road cut each year is a good method of estimating the short term erosion quantity. Other methods may be employed also to measure short term rates, such as sediment troughs or sedimentation basins.

B. Long Term Average Annual Rate

For the same slopes in which a short term annual erosion rate was determined, a long term rate can be computed using the following expression:

$$\text{Long Term Annual Erosion} = \frac{\text{Total Quantity of Eroded Material}}{\text{Two Years (or more)}}$$

The fractions of a year are expressed in their decimal equivalent. For example, four years and six months would be recorded as 4.5 for computation purposes. The results are reported in tons/year or cubic yards/year.

In order to develop an erosion rate for use on proposed slopes, however, the area must be included. For instance, if it was desirable to develop a rate for a new slope from an existing slope, the rate on the existing slope would have the units tons/sq.ft./yr. To determine the total tons of sediment that would erode annually from the new slope, the area of the proposed slope would be multiplied by the reported rate for the existing slope. The result would thus have the units tons/year.

If rates have been computed for individual sections of a slope, the parts are summed to arrive at the total rate.

A road slope shown in Figure 3 is analyzed below to illustrate the procedure for computing long term and short term erosion rates.

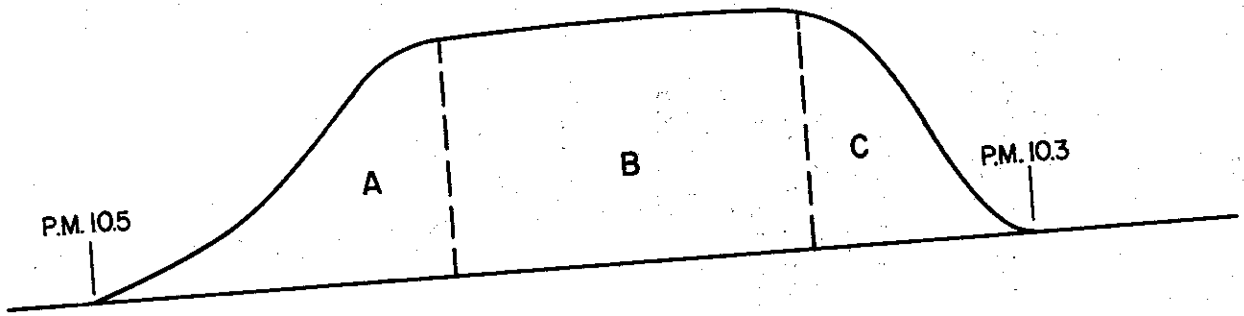


Figure 3 SLOPE EROSION RATES

The following data was derived from the survey:

	A	B	C
Area	800 sf	1600 sf	400 sf
Pct of Total Area	29%	57%	14%
Qty of Long Term Erosion	8 cy	16 cy	4 cy
Period of Long Term Erosion	8 yrs	8 yrs	8 yrs
Qty of Short Term Erosion	1 cy	4 cy	0.25 cy
Period of Short Term Erosion	1 yr	1 yr	1 yr

Calculations

1. Average Annual

	A	B	C
Long Term Yield	8/8 = 1 cy/yr	16/8 = 2 cy/yr	4/8 = 0.5 cy/yr
Long Term Erosion Rate	1/800 = .00125 cy/sf/yr	2/1600 = .00125 cy/sf/yr	.5/400 = .00125 cy/sf/yr
Short Term Yield	1/1 = 1 cy/yr	4/1 = 4 cy/yr	.25/1 = 0.25 cy/yr
Short Term Erosion Rate	1/800 = .00125 cy/sf/yr	4/1600 = .0025 cy/sf/yr	.25/400 = .00062 cy/sf/yr

2. Total Slope Erosion Rates

Long Term Rate = (.00125)(.29) + (.00125)(.57) + (.00125)(.14) = .00125 cy/sf/yr

Short Term Rate = (.00125)(.29) + (.0025)(.57) + (.00062)(.14) = .00188 cy/sf/yr

A comparison of the short term annual erosion rate with the long term shows that the former is greater than the later. Thus, erosion may be increasing but this conclusion cannot be drawn with certainty until other factors are investigated such as precipitation, etc.

The method for determining the quantity of eroded material during a field investigation is covered in the following section.

2. Use of Form HMRT-703

To aid in the determination of field estimates of slope erosion, Form HMRT-703 can be used. The information normally required to perform the survey can be readily entered in the appropriate column headings.

The heading block should always be entered with the proper information. This can be done before reaching the field by referring to appropriate U. S. Geological Survey Quadrangle Maps or equivalent. For purposes of the highway survey, the Basin refers to the major drainage basin such as Sacramento River Basin, etc. Watershed is normally the next lower unit for the particular drainage which is currently being studied and the small watershed in which drainage water from the road cut enters is the name of the Subunit.

The definitions for all of the required entries on Form HMRT-703 are given on the pages following the Form.

ROAD EROSION TRANSECT SURVEY

BASIN ______________________ DATE ______________________

WATERSHED ______________________ PARTY ______________________

SUBUNIT ______________________ LOCATION: T____ R____ S____ B & M ______________

ROAD DESCRIPTION ____

START POST MILE ______________________ END POST MILE ______________________

ODOMETER READING		EQUIVALENT POST MILES		DISTANCE	CUT / FILL	ASPECT	HEIGHT OF CUT	AREA	DEPTH EROS-ION	VOLUME - C.Y.		REMARKS
START	END	START	END		RIGHT / LEFT	ANGLE	FEET	S.F.		YR. DISPL. / TO STR.	YR. DISPL. / TO STR.	

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ROAD EROSION TRANSECT SURVEY

Basin - The Basin in which several watersheds drain, i.e., Sacramento River Basin, Lake Tahoe Basin, etc.

Watershed - The one specific drainage area generally identified by one major river or stream.

Location - Identify by Township, Range, Section, and 1/4 Section, if possible, and with reference to appropriate Base and Meridian. This information is useful to others regardless of their proximity to the project.

Road Description - Identify physical features of the road facility, i.e., number of lanes, type of pavement, shoulders, grade, etc.

Start and End Post Mile - The mileage marker delineating the Watershed Boundary on the roadway.

Odometer Reading - Record the reading at the beginning and end of a slope under investigation.

Equivalent Post Miles - Odometer reading referenced to the start and end Post Miles.

Distance - Mileage difference between start and end recorded along slope (convert to feet for expediency and calculating erosion volumes).

Cut or Fill - Use C for Cut and F for Fill.

Right or Left - Use R for slope location on Right and L for slope location on Left. Right and Left is determined by facing in direction of increasing Post Miles.

Aspect - Indicate N (North), S (South), E (East), W (West), facing slope.

Angle - Estimate of the slope angle, i.e., 1 1/2:1, 4:1, etc. or use measured angle.

Area - Estimate the surface area in square feet of slope undergoing erosion.

Depth Erosion - Estimate of average depth of erosion on slope for period under investigation.

Volume (CY) -

(1) Determine an annual rate for latest year of cubic yards of eroded slope material and enter the volume under "DISPL" (Displaced) and record the year. Estimate the percentage that reaches a tributary stream or is likely to be available for sediment transport. Record in cubic yards under "To Str" (To Stream).

(2) Determine the volume of cubic yards of eroded material over a longer period of time than in (1) if sufficient evidence is available. Record the beginning year which volume is to be estimated from. Record cubic yards in "Displ". Again, estimate the quantity reaching tributary drainages and available for transport. Keep in mind potential changes that could have occurred over the period being estimated.

Remarks - Note any significant factors such as gully erosion, boulders on slope, cross drain near toe of cut, erosion in road ditch, vegetation established on 3/4 of slope, etc.

Remedial Measures - Make an estimate of possible remedial action that might be taken to reduce the erosion on this slope. For example, a stable top-of-cut ditch might reduce gully erosion, or establish vegetation on remainder of 1/2 slope, etc. These notes will assist future planning in the office.

In conducting the survey, the Post Mile limit immediately preceding the cut slope is correlated with the automobile's odometer reading if the mileage marker is a significant distance from the cut. In some cases, a post mile marker is located within or near the end of a cut slope where a culvert crosses the roadway and there is no need to correlate with an odometer reading. The equivalent or actual post mile points of the beginning and ending of the cut slope are determined.

If it is desirable to break the slope into smaller sections in order to estimate the total erosion quantity, a different row should be used for each section. Otherwise, one row can be used for the entire slope. The appropriate distance is recorded for the area under study as is the height of the section.

For example, if the cut slope shown in Figure 4 is being analyzed for erosion, the correct entries for distance and height of cut would be as shown. The three respective areas would be entered on separate rows under the column headed "Area (S.F.)".

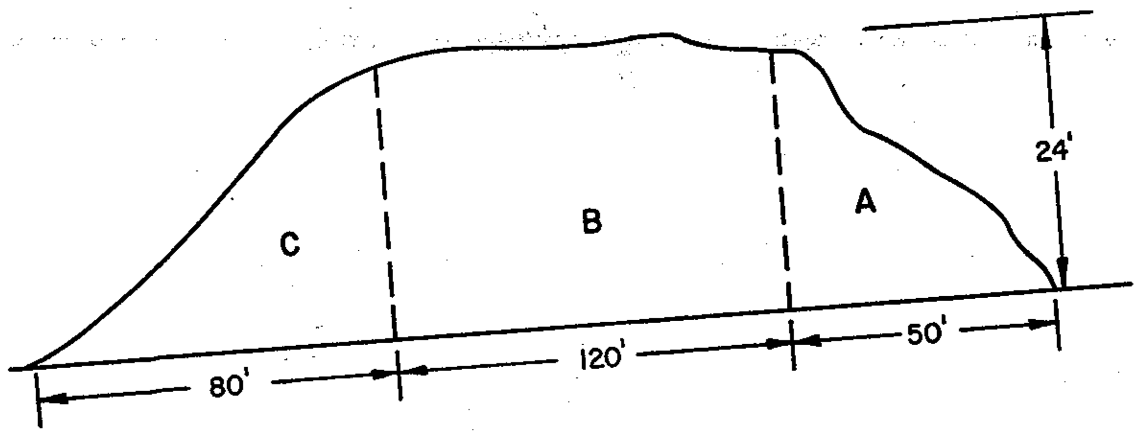
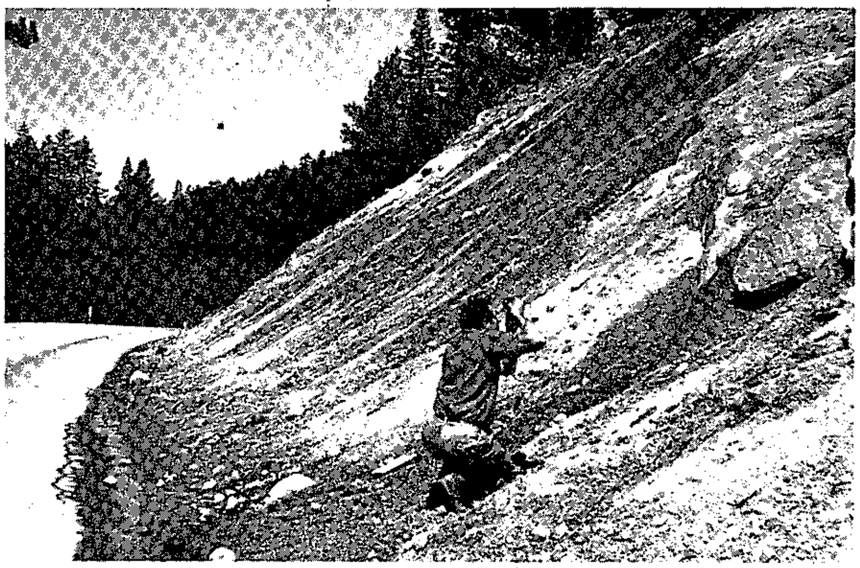


Figure 4 AREA COMPUTATION

Segment	Length	Ave. Height	Area	% Total
A	50'	12'	600 sf	13
B	120'	24'	2880 sf	65
C	80'	12'	960 sf	22
			4440	100

The aspect of the slope and slope angle can be determined using a Brunton-style compass. This information is also recorded on the form.



DETERMINING SLOPE ANGLE USING BRUNTON-STYLE COMPASS

This information is useful when estimating probable erosion quantities from future slopes that may have the same angle and aspect (exposure).

Using erosion signatures as discussed under Procedure For Slope Erosion Transect Survey, a depth of erosion can be estimated for a particular representative area or an actual volumetric measurement can be made. If a depth determination is made, the estimate is recorded in feet under the column headed "Depth Erosion". Long Term and Short Term rates are either entered under the column headed "Volume - CY" or on separate row entries. A long term and short term rate may not be possible to determine for all slopes. The final volume is entered for "DISPL" which means that is the quantity of eroded sediment displaced from the slope for a specified time period.

The time period can either be entered by total number of years elapsed or by indicating the year in which the slope was known to have been built, etc.

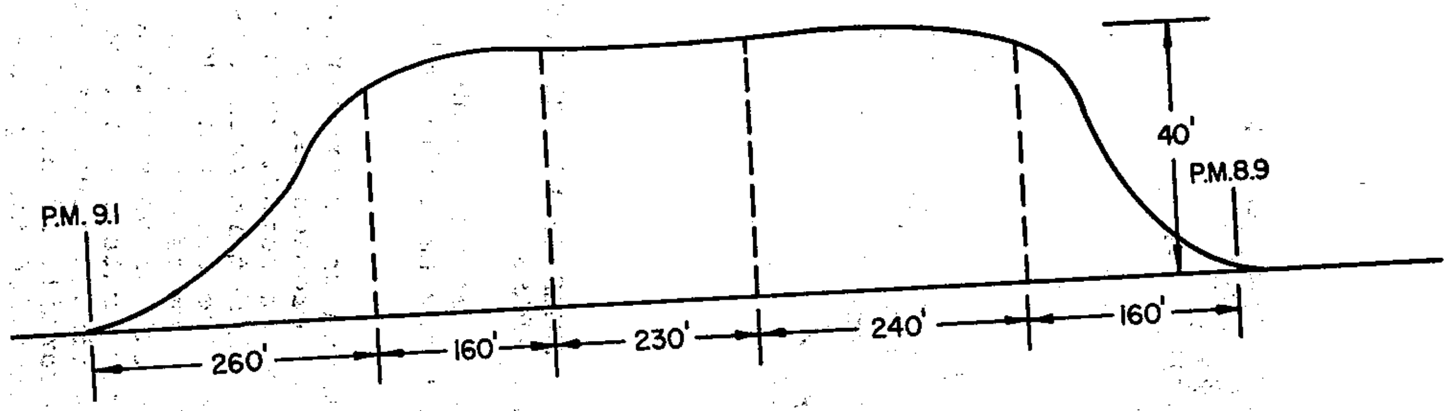


Figure 5 EXAMPLE PROBLEM OF SLOPE EROSION SURVEY

Segment			Area,sf	% Total
A	1/2 x 260 x 40	=	5200	15
B	160 x 40	=	6400	19
C	230 x 40	=	9200	27
D	240 x 40	=	9600	29
E	1/2 x 160 x 40	=	3200	10
			33,600	100

An example of a typical survey is presented to recapitulate the major points.

As an example, suppose a slope erosion survey was conducted on a slope that was constructed 8 years ago as shown in Figure 5. The west facing slope had an angle of 2:1 and is located on the right side of the road. The slope is broken into five sections as shown and the computation of the respective areas are indicated. This information is entered on Form HMRT-703.

Erosion signatures were examined on each segment with the following results:

Area A

Uniform erosion with an estimated 2 inches of soil removed since construction. Short term erosion signatures revealed about 2 cubic yards of material were eroded during the past year.

$$\text{Long Term} = \frac{5200 \text{ sq.ft.} \times 0.17 \text{ ft.}}{27 \text{ ft.}^3/\text{cy} \times 8 \text{ yrs.}} = 4.1 \text{ cy/yr; Short Term} = 2 \text{ cy/yr}$$

Area B

Several rills and gullies with small overhang near top of slope. A volumetric measurement indicates approximately 40 cubic yards of eroded material since construction. It appears that about 5 cubic yards were eroded during the past year.

$$\text{Long Term} = \frac{40 \text{ cy}}{8 \text{ yrs.}} = 5 \text{ cy/yr; Short Term} = 5 \text{ cy/yr}$$

Area C

Similar signatures as Area B but gullies are a little deeper. Volumetric measurements show 60 cubic yards of eroded material since construction. During the past year, it appears that about 8 cubic yards were eroded.

$$\text{Long Term} = \frac{80 \text{ cy}}{8 \text{ yrs}} = 10 \text{ cy/yr; Short Term} = 8 \text{ cy/yr}$$

Area E

More uniform erosion occurred over most of slope with small rills evident. Erosion signatures indicate that approximately 3 inches of erosion had occurred since construction. On short term basis, approximately 1/2 inch was eroded.

$$\text{Long Term} = \frac{3200 \text{ sq.ft.} \times .25 \text{ ft.}}{27 \text{ ft}^3/\text{cy} \times 8 \text{ yrs}} = 3.7 \text{ cy/yr}$$

$$\text{Short Term} = \frac{3200 \text{ sq.ft.} \times .042 \text{ ft.}}{27 \text{ ft}^3 \text{cy} \times 1 \text{ yr.}} = 5 \text{ cy/yr}$$

Total erosion rates are as follows and are entered in the column headed "Volume-CY" on Form HMRT-703:

	Long Term	Short Term
Area A	4.1	2.0
Area B	5.0	5.0
Area C	7.5	5.0
Area D	10.0	8.0
Area E	3.7	5.0
Total	30.3 cy/yr	25 cy/yr

An analysis of the two erosion rates indicates that during the past year slope erosion has decreased somewhat from the long term average rate. This may be due to several different factors such as decreased rainfall, etc., and must be explored further if it is desirable to determine the cause.

To determine the erosion rate per unit area that can be applied to unconstructed slopes, the following computations are made. First, the rate per unit area is determined for Sections A through E. The rate is then multiplied by the ratio of that area to the total area. The total of these computations represent the weighted average annual erosion rate per unit area.

	Long Term Rate/SF			Ratio of Subarea to Total Area		CY/SF/YR
A	$\frac{4.1}{5200}$ = .00079		x	.15	=	.00012
B	$\frac{5.0}{6400}$ = .00078		x	.19	=	.00015
C	$\frac{7.5}{9200}$ = .00082		x	.27	=	.00022
D	$\frac{10.0}{9600}$ = .00104		x	.29	=	.00030
E	$\frac{3.7}{3200}$ = .00116		x	.10	=	.00012
		Weighted Average			=	.00091

ROAD EROSION TRANSECT SURVEY

BASIN Sacramento
WATERSHED Pitt R.
SUBUNIT Burney Cr.
ROAD DESCRIPTION Two-laned Paved Road

DATE August 15, 1968
PARTY T. Jones S. Albert J. West
LOCATION: T___ R___ S___ B&M___

START POST MILE 8.9
END POST MILE 9.1

ODOMETER READING START	ODOMETER READING END	EQUIVALENT POST MILES START	EQUIVALENT POST MILES END	DISTANCE	CUT/FILL — RIGHT/LEFT	ASPECT/ANGLE	HEIGHT OF CUT FEET	AREA S.F. ×10	DEPTH EROSION	VOLUME-C.Y. YR. 8 DISPL./TO STR.	VOLUME-C.Y. YR. 1 DISPL./TO STR.	REMARKS
A		9.1		260'	C / R	W / 2:1	40	52	2"	4.1	2	Long Term = $\frac{5200 x .17}{27}$ = 32.8
B				160'	C / R	W / 2:1	40	64	-	5.0	5	
C				230'	C / R	W / 2:1	40	92	-	7.5	5	
D				240'	C / R	W / 2:1	40	96	-	10.0	8	
E			8.9	160'	C / R	W / 2:1	40	32	3" / .5"	3.7	5	Long Term = $\frac{3200 x .25}{27}$ = 29.6 Short Term = $\frac{3200 x .043}{27}$ = 5
							TOTAL	ANNUAL =		30.3	25.0	

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Similar calculations for the short term rate yields a value of .00076 cy/sf/yr. The investigator must now interpret which rate to use on the unconstructed slope.

If it is desired to estimate the average annual slope erosion on an unconstructed slope with similar characteristics as the slope surveyed in the example above and the area of the new slope is calculated to be 45,000 square feet, the rate would be (using the Long Term Rate):

.00091 cy/sf/yr x 45,000 sf = 41 cy/yr.

3. <u>Summary of Method</u>

The major impact resulting from highway facilities generally is erosion and subsequent sedimentation. This impact is classified as physical contamination. Investigations have revealed erosion of highway slopes to be a significant contributor of sediment in streams and lakes.

Erosion of barren slopes occurs through raindrop impact and by surface runoff. In some regions of the State, where annual precipitation is less than 10 inches, wind is the major erosive agent.

Gully and rill erosion are the most obvious types observed. This is so because they leave scars on the landscape. Sheet erosion, however, is also a predominant erosion type. It occurs uniformly over the surface of a slope and is thus more difficult to detect for the untrained eye.

An estimate of the probable amount of erosion on highway slopes for a specified period of time can be performed through a field survey. Information relating to soil type, degree of vegetative cover, topography, potential rain-fall intensities and duration, etc., need to be gathered. Investigation of existing slope erosion through a slope erosion transect survey is a good method for predicting annual erosion rates.

In conducting the investigation, the post mile limits of the cut or fill slope under study are recorded and the area of the slope undergoing erosion computed. A Brunton-style compass is used to determine the average slope angle. On many slopes, when the configuration is too irregular because of extreme erosion or protrusion of rocks to record an average slope angle, the angle is noted as variable.

The aspect of the slope is determined (north, south, east, or west-facing). The slope aspect has importance insofar as exposure to the sun, temperature, time period of extreme climatic conditions such as snow cover, and type of vegetation covering slopes are concerned.

In estimating the quantity of eroded material from a slope, a dual procedure is used. First, an estimate of the amount of erosion occurring over an annual period is made. This involves probing the slope surface for evidence of annual movement of material over the slope. One signature is pine needles, leafs or other similar material that are found buried under fractions of an inch of loose slope material thus indicating rate of soil deposition. Exposure of fresh plant roots also are used to determine annual rates of erosion as is the occurrence of coloration on rocks and boulders in the slope as material is eroded. Curvature of the main stem on woody plants also give clues as to the movement of material downslope.

The second procedure followed is to determine the amount of erosion occurring over a long period of time. Such a period might be anywhere from two to 15 years. The longer term periods such as 10 years or more are very difficult to ascertain and much reliance must be made to as-built plans, maintenance records, and memory of personnel working or living in the area. Long term erosion quantities are then reduced to average annual rates for comparison with the annual rates as determined under the first procedure. Sometimes, the two annual quantities are of the same order of magnitude. This indicates a stabilized erosion rate. Other times, the annual rate will be lower than the average annual rate which indicates initial erosion on the slope was extreme. The third case found is where the annual erosion rate is higher than the average annual rate which indicates changing conditions are accelerating the erosion on the slope. In the third case, it is important to look for the factors causing the accelerated erosion and perhaps to instigate remedial action to reduce the erosion.

The over-hang near the top of a cut can frequently be observed to assist in developing the long term erosion quantity. Clumps of rooted vegetation near the top of cuts provide a good indication of former slope profiles.

The results of the field survey are entered on Form HMRT-703. These results can be compared with other results from similar slopes to arrive at a rate that can be applied to the slopes that will be constructed on the new facility. In order to apply the estimated rates to planned slopes, rates should be selected that were derived from existing slopes having a similar aspect, slope angle, precipitation conditions, etc.

ESTIMATE OF SEDIMENT QUANTITY REACHING STREAMS

In some cases, it is useful to know the approximate quantity of eroded material that is actually transported from the road slope to a tributary stream each year. Several factors will influence the amount of movement, the most obvious being the quantity of water available as the transport vehicle.

Initial transport begins on the slope surface primarily from raindrop impact, surface runoff and gravitational forces. Eroded material is normally transported to the base of the slope more readily than it is from the base to a nearby drainage facility because the angle of the slope is much steeper than the grade line along the base of the cut. However, there is generally more water concentrated in the base drainage thus providing increased capability of transport in the flowing water.

In estimating the quantity of sediment that is actually transported to a specific point from the road slope, the drainage system should be reviewed to determine its capability of transporting a significant portion of the sediment. If there appears to be obstacles to transport such as debris barriers, undersized or plugged culverts, heavy vegetative cover in the drainage, there should be evidence of sediment deposition from past storm events. It is possible to compare the amount of material collected at these points to the previously determined rate of erosion and estimate the percentage that is not deposited or has reached the stream or lake. Judgment must be used in these cases because deposition may have occurred in several locations that are not readily discernable. Steep sloping areas with a minimum of hinderances to flow generally transport a significant quantity of eroded sediment to the stream. On the other hand, a circuitous drainage path that is fairly flat, which has numerous areas where sediment may be collected, may only transport a small percentage of the total eroded sediment on an annual basis.

In cases where it is extremely difficult to make an estimate, a sediment collection basin may be installed for a specified period of time to observe the rate of collection.

Another possible technique is to take suspended sediment and bedload samples in the drainage system and compute the total sediment rate using appropriate transport formulas. However, the use of this method requires knowledge of streamflow characteristics and an adequate depth of flow for the U. S. DH-48 depth-integrating suspended sediment sampler.

It is also possible to estimate the amount of erosion occurring in ditches and other drainage facilities while estimating the sediment quantity reaching streams. This information may be useful in deriving a total sediment quantity from runoff water emanating from a road slope.

For road slopes that are not located near a stream system, the percentage of eroded sediment entering the stream from the road slope decreases. During surveys of some slopes in the Tahoe Basin, it was found that practically no sediment from slope erosion reached a stream[3]. In other instances, where the road cut was located near a stream, there was almost no impedance to sediment transport and the relative amount entering the stream was quite high.

The precipitation that has occurred prior to taking the survey plays a large role in the amount of sediment actually transported. Below-average rainfall may transport relatively small amounts of sediment whereas the converse may be true for above-average precipitation. Sediment commonly will collect at specific points on its way to a stream for various periods of time. An above-average rainfall may yield sufficient runoff that is capable of transporting the sediment accumulated from previous storms. Therefore, it is desirable to have some knowledge of precipitation patterns prior to taking the field survey. This information will assist in making interpretations.

The percentage estimated times the displaced or eroded sediment can be entered on Form HMRT-703 in the column headed "Volume-CY" under "To STR" which stands for Sediment to Stream.

The percentage of eroded sediment from a road slope that annually enters a stream can also be applied to the proposed slopes in estimating sediment quantities that will impact waters associated with the new facility. Adjustments can be made to the percentage for differences in distance from slope to stream, gradient of drainage channel, impedance factors such as brush, etc. Care must be exercised in this process, however, to prevent minimizing a sediment transport rate beyond existing or measured rates. Used properly, this technique can provide a useful tool in determining sediment contributions to stream environments from a planned roadway.

USE OF SEDIMENT RATES IN ENVIRONMENTAL IMPACT STUDIES

The purpose for undertaking a slope erosion study is to identify the existing average annual rate of sediment per unit area that is contributed by a road slope that is similar to a proposed or an unconstructed slope on a new alignment. By determining these rates, it is possible to apply an adjusted erosion rate to the new slope taking into account precipitation, soil factors, topographic features, slope angle and aspect. Applying the adjusted rate over the area of the new slope face, a quantity of sediment can be determined that will, on the average, emanate from this slope each year. Further adjustments may be made to the sediment quantity in determining the percentage of this material that actually reaches a stream each year.

The type of soil material that will be exposed after the road cut is constructed can generally be determined from boring logs or other geologic mapping. Existing slopes should then be selected for the erosion transect survey that are similar to the material that is expected to be exposed.

The computed annual rate can now be compared with existing sediment transport rates in the stream under study. Procedures for conducting a stream suspended sediment sampling program are contained in previously published Materials and Research Report entitled "Analysis of Water Quality For Highway Projects"[14].

The following relationship can be used to compare these rates:

$$\% = \frac{\text{Sediment Reaching Streams Annually from Proposed Slopes (Tons/Year)}}{\text{Average Annual Suspended Sediment Yield of Stream (Tons/Year)}}$$

If the ratio is high, there may be a significant input of sediment from the highway source in comparison with existing background levels. Conversely, if the ratio is relatively low, the contribution from the proposed highway slopes may not be significant and thus the impact likewise may not be significant. It is important to stress at this point, however, in determining impacts one must investigate the downstream receptor or water user and ascertain if an additional quantity of sediment will impact that area or not. It may be that existing rates are already impacting the downstream user. Therefore, no general statements can be made in regards to determining a probable impact based on relative sediment contributions from highway sources compared to other sources. Each project must be analyzed based on probable sediment rates, average annual suspended sediment yields, downstream receptors including aquatic biota, future water uses and land use for upstream and downstream areas. Collectively, an opinion can be rendered on the significance of the impact based on the facts generated from the study.

It is also important to remember that subjective judgments are used in estimating rates on existing road slopes and in relating these rates to the planned slopes. In so doing, a degree of error may be introduced and if the watershed under study requires more detailed information entailing additional manpower or time, a more comprehensive study can be undertaken using sediment troughs, sediment collection basins, etc. The data developed from a more detailed study will likewise provide more refined answers.

However, for most studies, the slope erosion transect survey will provide a rapid means of generating sufficient sediment information that can be used to determine sediment contributions from future road slopes. This is particularly true for water quality studies conducted during the planning stages where several alternative alignments are under consideration.

If a significant quantity of sediment is estimated from the proposed road slopes, mitigation measures can be instituted by the designer to reduce that rate.

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